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## APPENDIX B

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### Sample Measurement Units, Activity and Mass

#### Introduction

Typically units of decay rate instead of mass are used to quantify the concentration of radioactive material in soil because the carcinogenic risks of exposure to soils contaminated with radioactive materials are related more to the decay rate of the material than to its mass. For example, one gram of  $^{226}\text{Ra}$  has a decay rate (activity) of  $3.7 \times 10^{10}$  transformations (also referred to as disintegrations) per second, while one gram of  $^{137}\text{Cs}$  has a decay rate of  $3.2 \times 10^{12}$  transformations per second. Since it is the energy emitted by the radioactive material during radioactive decay and the frequency of the decay that is usually of public health concern, and generally not the chemical properties of the radioactive material, it is more meaningful for health assessment purposes to quantify radioactive material according to decay rate. In addition, radioactive materials are detected and quantified by the type of radiation emitted and number of disintegrations (per unit time), not by their unique chemistry, as is the case for non-radioactive material. For these reasons, the concentration of radioactive material in soil is typically expressed in units of decay rate, pCi/g.

#### When and How to Calculate Mass

The equations presented in this TBD and the User Guide calculate SSLs for radionuclides in the traditional units of pCi/g. Mass units, however, provide insight and information into treatment selection, treatment compatibility, and treatment efficiency, particularly for remedial actions involving mixed waste. For example, remediation goals expressed in mass are important for designing and evaluating treatment technologies such as soil separation, pump and treat, as well as subsurface barriers. Typically units for expressing mass in environmental media for soil and water are mg/kg for soil and mg/l for water. These mass units also can be expressed as parts per million (ppm) for soil and water, which is equivalent to mg/kg and mg/l. SSLs in pCi/g may be converted to mg/kg, and MCLs in pCi/l may be converted to their mass equivalent in mg/l, by the following equations:

$$SSL(\text{mg/kg}) = 2.8 \times 10^{-12} * A * T_{1/2} * SSL(\text{pCi/g})$$

$$MCL(\text{mg/l}) = 2.8 \times 10^{-15} * A * T_{1/2} * MCL(\text{pCi/l})$$

where  $2.8 \times 10^{-12}$  for soil or  $2.8 \times 10^{-15}$  for water is a conversion factor, A is the radionuclide atomic weight in g/mole, and  $T_{1/2}$  is the radionuclide half-life in years. To put the relationship between SSLs expressed in these units into perspective, examine the SSL in mg/kg corresponding to a SSL of 1 pCi/g for a long-lived radionuclide such as  $^{238}\text{U}$  and a relatively short-lived one such as  $^{60}\text{Co}$ .  $^{238}\text{U}$  has a half-life of  $4.51 \times 10^9$  y, so a 1 pCi/g SSL would be equivalent to 3 mg/kg. On the other hand, a 1 pCi/g SSL for  $^{60}\text{Co}$ , which has a half-life of 5.26 y, is equivalent to about  $1 \times 10^{-9}$  mg/kg. As noted in Attachment C, Table C.1, most

radionuclides, for which generic SSLs have been calculated, have half-lives ranging from a few years to 10,000 years. Appendix A in the TBD shows that most SSLs for radionuclides are in fact less than 1 pCi/g so the equivalent SSL mg/kg values are even smaller. Therefore, at SSL levels, the masses of most radionuclides are extremely small values. Attachment D in the User Guide also provides the mass equivalent values for the MCLs.

## **Background Information on Using Mass**

One important issue associated with using mass to characterize the quantities of radioactive material in the environment is that many elements, such as uranium, have several isotopes of the same element. For example, if one were to perform atomic absorption analysis of a water sample, and it revealed the presence of 1 mg/kg of uranium, there would be no way of knowing how much of the uranium in the sample is  $^{238}\text{U}$ ,  $^{234}\text{U}$ , or  $^{235}\text{U}$ , all of which are present in the environment naturally and due to anthropogenic activities. The potential public health and environmental impact of a given concentration of uranium in the environment will depend on the specific isotopes of uranium that are present, which could vary considerably depending on whether we are dealing with naturally-occurring uranium or uranium that may have been enriched in  $^{235}\text{U}$  as part of the uranium fuel cycle or part of weapons production. It is also important to note that the same mass of each uranium isotope has significantly different levels of radioactivity. A mass of 1 mg/kg of  $^{238}\text{U}$  has an activity of 0.33 pCi/g, while the same mass of  $^{235}\text{U}$  has 2.1 pCi/g and 6,200 pCi/g of  $^{234}\text{U}$ .

Also, many radioactive elements are present in the environment along with their stable counterpart. One example is potassium, which is naturally-occurring in the environment, ranging from 0.1 to 1% in limestones to 3.5% in granite. In addition, a typical 70 kg adult contains 130 g of potassium. A very small fraction (0.01%) of this potassium is the naturally-occurring radioactive isotope  $^{40}\text{K}$ . If one were to measure the amount of  $^{40}\text{K}$  in soil and assume that  $^{40}\text{K}$  made up all of the elemental potassium, the mass of the elemental potassium would be underestimated by 10,000 fold.

Since the potential adverse effects of radioactive material are due to its disintegration rate, measurement of the mass of a given element present may not accurately represent the amount of radioactivity present and, therefore, its potential radio-toxicity.

## **Use of Mass in Remediation and Technology Selection**

The measurement of the radioactivity present often will be a misrepresentation of the total mass of the given element and should not be used alone to calculate the treatment required for remediation technologies, since technologies are essentially chemical/physical. Doing so may underestimate the total mass of the given element and lead to errors in the amount of treatment or reactants required for remediation since technologies are chemically/physically based. For example, to design and implement a subsurface Permeable Reaction Wall for the Uranium isotopes described above, it would be necessary to know the total mass of the Uranium isotopes as well as the other aqueous reactive elements to calculate the equivalent amounts of sorption or precipitation reactants that would be required to remove or reduce the aqueous Uranium species from contaminated groundwater (EPA 2000a & EPA 1999a). The same considerations would be necessary for other ground water or water treatment technologies for dissolved concentrations of elements and their isotopic forms. For example in a pump and treat ground water extraction system that utilizes ion exchange (chemical separation) or reverse osmosis (physical separation), chemical mass measurements would be used to determine the amount and type of reactants materials, exchange capacity and effectiveness (EPA 1996). Much the same can be said for mobility limiting or mobility reduction technologies such as chemical

solidification/stabilization treatability studies or treatments (EPA, 2000b). Also, mass measurements are important in the determination of Partition coefficients,  $K_d$  values that are essential in fate and transport, risk assessment modeling, and remediation calculations.  $K_d$  values are expressed in mass units for the inorganic elements and isotopes (EPA 1999b). Partition coefficients,  $K_d$  values, are the same value for all forms of the element and isotopes.

In summary, given that risk or exposure is the basis for remedial actions, mass measurements are often required for determining, designing and selecting a remediation technology. This contrasts with the need for radiation specific isotopic measurements required in risk and exposure analysis. Users should note the different applications and perspectives with their corresponding measurements units of mass and activity.

## References

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